Exhibit 1

Technical Certification by Gorca Systems Inc. of a Comparison of FDMA and CDMA for the Small LEO Satellite Applications

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Introduction

On September 26, 1991 the Federal Communications Commission (FCC) adopted a notice of proposed rule making (NPRM) with regard to Low-Earth Orbit (LEO) satellites utilizing a small amount of spectrum in the VHF and UHF bands. These small LEO satellites will provide consumers a variety of low cost data messaging and position determination services using inexpensive portable personal radio communication units.

Orbital Communications Corporation (ORBCOMM), STARSYS Inc. (STARSYS), Volunteers in Technical Assistance (VITA), and LEOSAT Inc. (LEOSAT) have filed to provide LEO satellite services in the frequency bands of 137-138, 148-150.05, 399.9-400.05 and 400.15-401 MHz. In order to provide optimum access to these frequency bands to each of the applicants, we evaluated the pros and cons of their proposed systems. Based on our analysis and with some reasonable set of assumptions, we concluded that the Code Diversity Multiple Access (CDMA) modulation using direct sequence Pseudo-noise (PN) spread spectrum technique in the 137-138 and 148-150.05 MHz band will provide the maximum capacity as compared to the single-channel-per-carrier (SCPC) Frequency Division Multiple Access (FDMA).

Therefore, the recommended CDMA (PN) approach offers more channel capacity than FDMA/SCPC techniques, and depending on the individual traffic characteristics, it will allow applicant services to co-exist. We are describing a data service (non-voice), which is based on short bursts of 150 msec (or less).

Background

Many access methods are available for use in LEO satellite systems and the question naturally arises as to which one, or ones, are best suited to the application. Ultimately the choice depends upon the relative service costs and performance. System communication's capability and equipment costs (space and ground) are major factors in determining service costs, assuming equivalent performance in all cases. Here we examine the issue of system capacity for the two most promising methods (FDMA and CDMA), tacitly assuming that with mass production of commercial equipment, the equipment costs will be comparable.

Significant constraints on the access method are imposed by the need to share the allocated spectrum with existing services and among LEO service providers. To do so, the multiple access method must not cause serious interference into receivers of the existing services by either its space-to-Earth transmissions or by its Earth-to-space transmissions. Further, it must accept any interference the existing services may inject into the LEO system. Also the access method must permit other LEO systems to operate in the same frequency bands.

Analytical Approach

The analysis is based on the following general assumptions:

1. The LEO satellite carries a "bent pipe" transceiver: no processing is done in the transceiver, all receiver signals are amplified,

frequency translated and rebroadcast. (However, the analysis is applicable if some on-board processing is carried out by the satellite thus affecting only the complexity and hence cost of the satellite.)

2. The communication system architecture uses a star configuration. Subscriber terminals, e.g., mobile terminals, communicate with a hub terminal only,ie, no communications between mobile to mobile terminals is assumed.

3. All uplink transmissions from the subscriber terminals (inbound) and the hub terminals (outbound) are in a 1 MHz segment of 148-150.05 MHz band.

4. Similarly, all downlink transmissions are in the 137-138 MHz band.

5. Data are transmitted in bursts.

6. Data are encoded to provide error correction coding and to thereby reduce the carrier power required to attain a given bit error rate.

7. Opposite sense polarizations can be used on the LEO systems to achieve some (minimal) isolation between systems. However, this feature is not taken into consideration for the analysis.

Constraints imposed on the systems are the following:

1. Interference into existing systems must not significantly interfere with their operation.

2. Interference from existing systems into the LEO systems must not preclude LEO system operations.

3. Simultaneous multiple LEO system operation in the same band must be possible.

Specific assumptions are:

1. The transmissions from the subscriber terminal are bursts with the following parameters:

Message length	= 32 bytes, 8 bits/byte
	= 256 bits
Address	= 24 bits
Overhead	= 231 bits
Synchronization	=50 bits
Total Message Length	=561 bits
Burst Duration	= 150 m sec
Bit Rate/Burst	=3740 bits/sec
Bandwidth Required	=7480 (BPSK modulation)
E_b/N_o	= 6 dB

2. Since the LEO satellite transponder is a bent pipe type, the maximum usable bandwidth is that of the space-to-Earth allocation which is 1 MHz.

Brief Description of FDMA and CDMA

FDMA

FDMA systems (as proposed by ORBCOMM) are based on dividing the usable spectrum in to separate distinct channels, usually contiguous but not necessarily so. For example, the system analyzed here, an estimated 500 KHz of spectrum is available within the proposed allocation of 1 MHz bandwidth, the rest is expected to be occupied by the existing services. This 500 KHz is divided into channels separated by 9,350 Hz as required by the burst bit rate, BPSK modulation and the guard bands. This gives about 53 FDMA channels. Because the spectrum occupied by the existing services is not contiguous neither are the FDMA channels. Every transmitter in the system wishing to transmit data is assigned to one of the 53 channels and burst its data over that channel. Many transmitters are assigned to each of the 53 channels and, since each can transmit independently, occasionally the bursts will overlap and have to be repeated. This interference limits the channel occupancy to about 20%[1] of the time. Higher occupancy would necessitate many retransmissions and reduce the channel throughput. The limiting channel capacity identified in the FDMA analysis would increase the probability of conflict, collision, and operational interference amongst the applicant services.

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(1) The figure of 20% assumes pure ALOHA multiple access techniques; other access techniques will yield different channel occupancy.

CDMA

Spread-spectrum type systems (as proposed by STARSYS) can facilitate sharing by occupying more bandwidth, reducing the spectral power density and by using processing gain to reduce the signal margin required. The ability to frequency share by many applicants is due to the non-destructive nature of a relatively low bit rate CDMA modulation and its resulting flat spectrum shape. The CDMA technique is more tolerant of the RF interference present in a multi-users (service) environment (Ref. 1)

Improved efficiency in communication is achieved using CDMA spread technique over the available bandwidth. The CDMA spreading provides for dilution of the signal energy for the given bandwidth resulting in a small power density at any point. Moreover, the signal spreading process enables the receiver to reject strong interference signals (undesirable) in proportion to the spreading gain.

The CDMA technique utilizes modulating the RF carrier with a spreading code, thereby spreading the signal over the entire bandwidth. Direct sequence spreading is used whereby the phase of carrier frequency is shifted by a random binary bit stream. This binary sequence is called pseudo-noise (PN). Direct sequence spread spectrum method is used for transmitting digital packets information. In this system, a correlator identifies and detects the signals in accordance with the applicable spreading code. The undesired signals differ statistically from the desired signal, thus the correlator will discriminate the matched stronger signal.

Summarizing, the advantages of CDMA over FDMA include:

- Lower interference
- Better channel capacity
- Lower point power density
- Improved likelihood of multiple service co-existence.

Comparison of FDMA and CDMA

A meaningful comparison of the Frequency Division Multiple Access and Code Division Multiple Access must take into account the particular environment of the LEO systems. Foremost among the environmental factors are the need to share the spectrum with existing systems and with other LEO systems. In an FDMA approach, the attempt is made to use channels not in use by other LEO systems or existing systems. In the CDMA approach, the objective is to coexist in the same spectrum with the other users.

A comparison of the *spectral efficiency* is used to evaluate the relative merits of FDMA and CDMA. *Spectral efficiency is defined as the data bits per second per Hz of available bandwidth.* The greater the spectral efficiency provided by the access technique the greater is the possibility of supporting multiple users, each with enough data capacity to support an economically viable system.

For the comparison of the FDMA and CDMA systems, the following data are used:

Available Bandwidth	1 MHz
Access Technique within FDMA Channels	ALOHA
Maximum FDMA Channel Utilization (est.)	20%
Data Modulation	BPSK
Code Rate	1/2
Code Type	CRC
E_b/N_0	6 dB
Satellite Access Power	The same for all users.

In the case of FDMA, the analyses are based on the use of one-half of the available bandwidth in the 137 to 138 MHz downlink. Approximately 428 KHz are allocated to existing users. Additional restrictions due to uplink allocations could bring the usable bandwidth to 500 KHz for LEO satellites. FDMA frequency plans would be such as to avoid use of spectrum containing existing users.

For CDMA, the analyses are based on the use of the full 1 MHz of available spectrum. The affects of the resulting interference into the LEO system are included in the analyses.

Gilhousen et. al. (Ref 2) compares CDMA system with the SCPC FDMA system and concludes that CDMA approach provides greater capacity for mobile satellite communication.

As mentioned earlier, a comparison of the spectral efficiency is used to evaluate the relative merits of FDMA and CDMA. Spectral efficiency is defined as the data bits per second per Hz of available bandwidth. The greater the spectral efficiency provided by the access technique the greater is the possibility of supporting multiple users.

Spectral efficiencies are based on the following equations adapted from those of Ref. 2.

FDMA Eff.	= F1 * F2 * (C/NoWf)/(Eb/No) bits/second/Hz
F1	= ALOHA channel utilization factor = 0.2
F2	= Wf/Ws = 500 KHz/1000 KHz = 0.5
Wf	=Total allocated bandwidth
Ws	= Total system bandwidth
C	= Total carrier power into receivers
No	= Total noise power density in to receivers
Eb/N_o	= Energy per bit to noise density ratio required

$$\text{CDMA Eff.} = \frac{1}{K} \frac{(KC/NoWs)}{[(E_b/(N_o + I_o + I_1)] * (1 + KC/N_o W_s)}$$

K	=	$1 + P_I/C$
P_I/C	=	Ratio of interference power from existing systems to total LEO system carrier power at input to LEO satellite system receivers
C	=	Total LEO system carrier power into LEO system receivers
N_o	=	Transponder input thermal noise
W_s	=	Transponder bandwidth
	=	Available bandwidth = 1 MHz
I_o	=	Intra-LEO system interference power spectral density, from other user accesses
I_1	=	Interference power spectral density from existing system
	=	P_I/W_s

Spectral efficiencies are given in Table 1. For CDMA the efficiency is shown as a function of K, a measure of the existing system interference power: K=1, no interference; K=2 interference is equal to the total signal power and for K=4 the interference is three times the signal power.

In Table 1, the FDMA column terminates at spectral efficiencies of 0.025 (2.5%). For parameter values used in the analysis, the FDMA system reaches its bandwidth limit at slightly less than that efficiency (2%).

Efficiencies for CDMA reach a limit of about 25% because as the C/N_oW_s ratio gets large, self interference dominates and further increases in carrier powers cause equal increases in interference level and there is no net gain in system capacity. In addition to the self interference limit the downlink power density, which translates to interference into existing systems will limit CDMA capacity. For a flux density objective of -140 dB w/m^2 / 4KHz the CDMA spectral efficiency and hence, capacity is about 20% assuming no interference from the existing systems.

The analyses summarized above indicate that the CDMA approach to LEO satellite access can support 5 to 10 times the traffic of FDMA, depending, importantly, on the interference from existing systems. That and other considerations, such as the specific access technique within the FDMA channels, interference into existing systems and specific parameters, should be included in the analyses to determine precisely the relative merits of FDMA vs CDMA.

CONCLUSIONS

More detailed analyses that take into account the spectral occupancy, the transmitted power levels and sensitivity to interference of the existing systems could modify the relative values as could the details of the various system designs and operations. However, this is believed to be a reasonable estimates of the relative capacity of the FDMA and CDMA systems. Based on the analyses and assumptions provided in this paper, it can also be concluded that the CDMA system will provide an economically superior solutions to the LEO satellite communications as compared to the FDMA system.

Table 1.

Spectral Efficiencies for FDMA and CDMA vs. Carrier to Noise Power Ratio

C/N_oW_s (dB)	FDMA	CDMA		
		K = 1	K = 2	K = 4
-12	0.00313	0.015	0.014	0.013
- 9	0.00625	0.028	0.025	0.021
- 6	0.0125	0.050	0.042	0.031
- 3	0.025	0.083	0.063	0.042
0	-	0.125	0.083	0.050
3	-	0.167	0.107	0.056
6	-	0.200	0.111	0.059
9	-	0.222	0.118	0.061
12	-	0.235	0.121	0.062
15	-	0.242	0.123	0.062
18	-	0.246	0.124	0.062
21	-	0.248	0.125	0.062

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in the Response of Leosat Corporation; that I am familiar with Parts 2 and 25 of the Commission's Rule and Regulations, and that it is complete and accurate to me best of my knowledge.

By: ______________________
S. Paul Sharma
Gorca Systems, Inc.

Date: 24 Dec. 1991

INTRODUCTION OF LEO SATELLITES BELOW 1 GHZ

Sharing in the Uplink Band

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K.Brown, September 1991

The US have proposed, and France has endorsed[2], spectrum allocations below 1 GHz to support (several) low Earth orbit satellite systems. The primary function of these systems is to provide inexpensive Doppler location for mobile terminals. While the promoters estimate that this type of system would be profitable if operated in the US alone, other administrations could also benefit. Canada in particular may find this service useful and in fact Telesat have conducted a Market/Business Evaluation (Aug.'91). TMI/MSAT also intends to offer location and communication service at L-band. However, it should be noted that there are many other satellite and land based position location facilities already in existence or in advanced planning and that some of the existing systems have failed financially.

The proposed uplink band for the LEO/MSS is 148-149.9 MHz, and the proposed downlink bands are 137-138 MHz and 400.15-401 MHz. Presumably, a separate antenna would be required for the 400 MHz band.

Traffic characteristics: location (Doppler), short messages (up to 100 characters, 70-250 msec), many users. This is <u>not</u> a cellular 'phone or FPLMTS type of offering.

SHARING IN THE UPLINK BAND

The French WARC'92 document[2] addresses sharing constraints on the LEO/MSS with respect to:

- Space Operations service (per FN 608);
  - pfd_{max} -142 dBW/m^2/4 kHz presumably at the satellite being commanded in the Space Ops service (i.e. in LEO, transfer orbit, GEO etc.);
- Mobile service;
  - CDMA LEO/MSS Earth stations (erp $\leq$3 dBW) coordination distance 1.4 km,
  - FDMA LEO/MSS Earth stations (erp $\leq$2.5 dBW) coordination distance 4.5 km ($\geq$9 dBW, $\geq$ 9 km per the JIWP Report);
- Radio Astronomy service (no allocation in the Radio Regulations);
  - unspecified combination of flux limits, frequency separation, geographic separation and time sharing;

- other LEO/MSS systems;
  - determined by sharing constraints to protect existing services plus spectrum and/or geographic separation, spectrally efficient modulation and access. The French study indicates that several CDMA systems are capable of sharing with each other and with existing services. FDMA realizations of the LEO/MSS do not readily share with each other, with CDMA realizations, or with existing services.

In Canada, the 148-149.9 MHz band is assigned (subject to Canada/US coordination) to Fixed services (primarily in rural areas) and to Mobile services (primarily in urban areas if other bands are unavailable (see Figure 1)). Priority is given to public and private paging and to civil emergency systems in the band 148.48-149.54 MHz. The following linkages need to be considered.

	Possible Interferers	ERP (dBW)	Source Channel Bandwidth (MHz)	
1.	Paging transmit(*d)	30 (maximum) 21 (typical)	15 kHz carrier spacing (secondary status)	
2.	FS transmit		$\leq$ 0.120 co-primary status > 0.120 secondary status	
3.	MS base station xmit(*a)	21 (maximum)	0.016 co-primary status	
4.	MS terminal xmit(*b)	15 (maximum)	0.016 co-primary status	
5a.	LEO terminal xmit[2]	3 3	1 0.009	(CDMA) (FDMA)
5b.	LEO terminal xmit[3]	3 (0 dBi) 9 (1.5 dBi)	1 0.0024	(CDMA) (FDMA)
6a.	LEO feeder xmit[2]	13.8 32	1 0.056	(CDMA) (FDMA)
6b.	LEO feeder xmit[3]	7.8 (10° beam) 25 (10° beam)	1 0.056	(CDMA) (FDMA)

	Possible Interferees	Sensitivity	Victim Channel Bandwidth (MHz)	
1.	Pager unit			
2.	FS receive	-120 dBW/m^2/4 kHz		
3.	MS terminal rcv(*c)	26 dBμv/m	0.016	(FM)
4.	MS base station rcv(*b)			
5.	LEO satellite rcv[2]		1 (+Doppler(*e)) 0.009 (+Doppler)	(CDMA) (FDMA)

Notes:

(*a) in simplex mode only, 149.020-149.890 MHz, 29 channels[6];

(*b) in duplex mode only, 148.015-148.975 MHz, 32 channels[6];

(*c) mobile units receive in both simplex and duplex bands, 148.015-149.890 MHz[6];

(*d) the most heavily used paging frequency is 149.770 MHz (328 licences out of a total of 751 in 3 major areas in Canada[1]);

(*e) maximum displacement due to Doppler effect approximately 3.5 kHz (TSC meeting 9 Sep.'91).

Links from potential interferer 1 to potential interferee 1 (1-1), 2-2, 3-3, 4-4, (3-4?), 4-3, 5-5, and 6-5 are wanted services (intra-service coordination).

Links 1-2, 1-3, 1-4, 2-1, 2-3, 2-4, 3-1, 3-2, 4-1, and 4-2 are presently coordinated services (inter-service coordination).

Links 1-5, 2-5, 3-5, and 4-5 (representing potential interference into the LEO/MSS) and 5-1, 5-2, 5-3, 5-4, 6-1, 6-2, 6-3, and 6-4 (representing potential interference into existing services) are new interfaces if the LEO/MSS is allocated to this band.

INTERFERENCE INTO THE LEO/MSS FROM EXISTING SERVICES

Qualitatively, the worst single entry situation with regard to operation of the new LEO satellite service is the 1-5 link (paging into LEO satellite receive) owing to the virtually 100% duty factor and high transmit powers of the paging service transmitters. However, the paging service amounts to only 8.5% of the licensed stations in the subject band and study areas[1] (note that, in the band 148.480-149.540 MHz, priority is given to public and private paging systems[6]).

The worst aggregate interference situation is the 3-5 link (mobile service base station into LEO satellite receive) due to the large number of mobile systems (44% of licences[1]) and the high power quasi-omnidirectional antennae of the mobile base stations. Frequency re-use constraints, traffic patterns and channel activity will limit the number of equivalent simultaneous potential interferers.

Assuming the traffic patterns of the LEO/MSS and existing fixed and mobile services (excluding the paging service) are similar, and assuming a 40% combined loading and activity factor for both the fixed and mobile services (excluding the paging service) during peak traffic periods, (the paging service consists of 751 transmitters out of a total 8780 mobile transmitters in Canada in the subject band[1]) the equivalent number of potential simultaneously transmitting equipments in Canada in the subject band is[1];

$$751 + 0.4 * (8780 - 751) \approx 4000$$

There are concentrations of these mobile transmissions in the urban areas thus, since there will be negligible angular discrimination from the satellite antenna, an individual LEO satellite may be in line-of-sight of several such concentrations at any one time (see example visibility areas in Figure 2). Transmit powers in the Mobile service vary considerably.

Interference Limiting Considerations

i The high power paging and mobile base station transmitters have a flat beam with the energy concentrated below the horizontal plane (up to 20° downward beamtilt is available on some antenna). Thus, some discrimination towards the LEO satellite is provided some of the time.

ii Similarly, in the Fixed service, there will generally be some antenna discrimination towards the satellite.

iii The satellite antenna may provide some discrimination to transmissions emanating from beyond the service area of the satellite. To minimize the number of satellites in the system assume some overlap of coverage from adjacent satellite earth tracks and further assume discrimination to the edge of visibility of 3 dB.

iv Terrestrial systems are typically vertically polarized while the LEO satellite system is likely to be circularly polarized so that a potential 3 dB discrimination may exist.

Interference into FDMA LEO/MSS

Assuming negligible contribution from the Fixed service or from the mobiles in the Mobile service (optimistic wrt interference potential), assuming an average erp of 21 dBW per paging or base station transmitter (pessimistic), assuming an activity/loading factor of 40% for the non paging services (pessimistic) and assuming the 61 mobile (or fixed) channels are evenly distributed over the band, the total peak accumulated transmit power (at 149.77 MHz) ignoring differential path losses is upper bounded by:

$$P_{acc} = 21 + 10\log_{10}(328 + 0.4*(8780 - 751)/61) - 3 = 43.8 \text{ dBW/15 kHz.}$$

Applying the same assumptions to the next most popular licensed paging frequency (148.795 MHz, 38 licences) the accumulated transmit power is less than:

$$P_{acc} = 21 + 10\log_{10}(38 + 0.4*(8780 - 751)/61) - 3 = 37.6 \text{ dBW/15 kHz.}$$

In channels which are only lightly used for paging, the corresponding accumulated power on this basis is less than:

$$P_{acc} = 21 + 10\log_{10}(0.4*(8780 - 751)/61) - 3 = 35.2 \text{ dBW/15 kHz.}$$

From Appendix 1, the differential path loss from sub-satellite to edge of visibility ranges from about 17 dB for a 250 m orbit to about 13 dB for a 750 km orbit with mean values 14.2 and 9.8 dB occurring at 67° and 62° off-axis respectively. If the edge of visibility is the 3 dB contour, these off-axis angles correspond to 2.4 and 2.1 dB satellite antenna discrimination respectively. The elevation angles corresponding to this mean path are 16.4° and 9.3° respectively which yield terrestrial base station antenna discriminations of about 3.2 and 1.1 dB respectively (ignoring beamtilt). Thus a crude estimate of the equivalent accumulated transmit power can be obtained by applying the mean path loss differentials to the above figures.

Thus, for a 250 km orbit, the maximum equivalent accumulated peak interference transmit power is about;

$$\begin{aligned} 43.8 - 14.2 - 2.4 - 3.3 &\approx 24 \text{ dBW/15 kHz near 149.770 MHz} \\ &\approx 18 \text{ dBW/15 kHz near 148.795 MHz} \\ &\approx 15 \text{ dBW/15 kHz in bands not used by paging} \end{aligned}$$

compared with a maximum transmit power from a wanted FDMA source of 3 dBW/9 kHz (or 9 dBW/2.4 kHz) near the sub-satellite point. It can be seen from this very crude 'analysis' that the uplink of a FDMA realization of the LEO/MSS could be subject to excessive interference if operated co-channel with the Fixed and Mobile services in the band 148 - 149.9 MHz. Interstitial operation may be less prone to interference but interstitial or split Fixed or Mobile service channels are also permitted subject to minor geographical constraints[1].

Since the present arrangement of prime channels and interstitial or split channels has carriers every 15 kHz in Canada, there is a possibility that the LEO/MSS could intersperse with these carriers. However, the US channelling plan has carriers every 12.5 kHz which would make selection of suitable interstitial slots for the FDMA LEO/MSS very difficult. Assuming the power spectrum of the fixed or mobile channels have a typical bell shape, the average power level of a 15 kHz wide channel at 7.5 kHz from the carrier would be negligible and the average power level of a 30 kHz channel at 7.5 kHz from the carrier would be reduced significantly from the peak value. Thus, in these circumstances, sharing between the existing FS and MS channels (15 or 30 kHz) and the offset FDMA LEO/MSS channels (9 kHz (plus 3.5 kHz Doppler displacement) per the French paper or 2.4 kHz (plus 3.5 kHz Doppler displacement) per the JIWP Report) in selected portions of the band may be more realistic. However, future growth of existing services may have adverse impacts on these selections (on the other hand, there is some indication that some present users may soon move to the 800 - 900 MHz region). Note that the interference potential in the other direction, FDMA LEO/MSS into FS or MS, would also be reduced from the co-carrier case by this interstitial arrangement.

The question of front-end overload of the satellite receiver in the presence of unwanted high power signals in-band needs further consideration. The dynamic range is anticipated to be of the order 80 dB so that this should not be problem for a low noise amplifier with good linearity.

Interference into CDMA LEO/MSS

In the CDMA realization there is no need to consider individual frequencies. It is the total number of simultaneous transmissions in the CDMA band that is critical. Since the total band is nearly 2 MHz wide, a 1 MHz wide CDMA channel will encompass half the available Fixed and Mobile service channels. Thus, in the upper 1 MHz band which also encompasses the heavily used 149.770 MHz paging channel, the equivalent interfering power is upper bounded by:

P_{acc} = 21 + 10log$_{10}$(number of paging transmitters in band + pro-rated number of mobile transmitters in band) - polarization discrimination - mean path loss differential

$$= 21 + 10\log_{10}(440 + 0.4*(8780 - 751)/2) - 3.0 - 19.8 \approx 31 \text{ dBW/MHz}.$$

In the lower 1 MHz band, the equivalent accumulated interference power is virtually the same since the number of paging transmitters is 751 - 440 = 311. These figures demonstrate that a CDMA realization with a reasonably high coding gain, error correction capability, etc. could possibly operate in the existing environment.

INTERFERENCE FROM LEO/MSS INTO EXISTING SERVICES

With respect to potential interference into existing services due to the introduction of LEO satellite services, the worst situation is not so obvious. It is probable that link 5-4 (LEO/MSS mobile Earth station transmit into MS base station receive) takes this honour since the LEO/MSS terminals can be located anywhere and the mobile base station receiver is the most sensitive of the existing services receiver types.

Interference from FDMA LEO/MSS

In this scenario, co-channel operation of the mobile system and the FDMA realization of the LEO/MSS in the same vicinity would give the worst single entry exposure. However, the duty cycle of a queue of co-channel LEO/MSS users would be small and geographically dispersed so that the net interference exposure would be small. The interference would be experienced as a set of randomly spaced clicks (burst duration 250 ms) of different magnitudes reflecting the different path losses, fades and gains from the various LEO/MSS terminal locations and the different carrier frequencies within the MS FM channel (9 kHz channels for LEO/MSS mobile terminals, 56 kHz channels for LEO/MSS feeder stations, 16 kHz channels at 30 kHz carrier spacing for MS (interstitial carriers possible)). The French contribution determines that an individual LEO/MSS FDMA terminal with a transmit power density of -37 dBW/Hz sited within about 4.5 km of a mobile terminal or base station could exceed the maximum allowable interfering field strength which in turn is determined as being 10 dB down on the required median field strength of the wanted signal. By comparison, the JIWP Report parameters yield a minimum interfering field strength for a FDMA transmitter of -25 dBW/Hz corresponding to a coordination distance of about 9 km. As pointed out above, offset operation would permit a higher allowable interfering field strength thus easing any coordination requirements.

Interference from CDMA LEO/MSS

In the CDMA realization of the LEO/MSS, theoretically every simultaneous LEO/MSS terminal transmission (burst duration 70 ms) interferes with every existing service in the 1 MHz CDMA band to a degree that is dependant upon the geographic separations. The per channel exposure of the existing terrestrial services to this realization is also likely to be small due to short message lengths and the geographic dispersion of the LEO/MSS terminals. In this case, the interference would probably be manifested as a small increase in background noise and therefore only of consequence during fades of the wanted signal. The French contribution determines that an individual LEO/MSS CDMA terminal with a transmit power density of -57 dBW/Hz sited within about 1.4 km of a mobile terminal or base station could exceed the maximum allowable interfering field strength. The CDMA realization would have to take account of the trade-off between interference immunity and the maximum number of simultaneous users on the LEO/MSS system.

RETRANSMISSION OF UPLINK INTERFERENCE IN THE DOWNLINK

The problem of retransmission of the interfering uplink band FS and MS emissions in the downlink arises in a "bent pipe" type of satellite for both modes of the LEO/MSS. In other satellite/terrestrial service sharing situations, the uplink interference is typically at a much lower level than the wanted signal so that the impact on shared services of retransmission of this interference in the downlink can be ignored. In the case under discussion however, both for the interstitial FDMA realization and the spread spectrum CDMA realization, the level of the LEO/MSS wanted signal is considerably lower than the level of the interfering FS and MS emissions. Since there is no requirement for direct mobile to mobile connection, this mode of interference would be apparent in the satellite to base station links which would be in the FSS so that, assuming that it would not be practical to remove it in the satellite, it would have to be considered during coordination of the base stations. Base station processing in the form of a comb filter for the FDMA realization and auto-correlation for the CDMA realization could remove this source of interference in the LEO/MSS.

LEO/MSS INTELLIGENCE (FDMA REALIZATION)

The JIWP report states that, for the LEO/MSS, "... it is expected that no unacceptable interference will be caused to the existing services. It is assumed that the development of the LEO systems will take account of possible interference from these existing services." For the FDMA realization, the second statement implies that, for its own protection, a LEO satellite system may have sufficient intelligence to dynamically assign low interference uplink channels. In so doing, protection to existing system receivers of the *heavily utilized* channels would be preserved but there is no guarantee that *lightly used* channels will be similarly protected. It is possible that the LEO/MSS intelligence combined with ultra sensitive and selective channel monitoring equipment could achieve both protection to itself and protection to existing services but these conditions could be in conflict unless technical constraints are defined for the LEO/MSS transmitters. Furthermore, such a sophisticated monitoring facility on the galaxy of satellites would be extremely expensive to implement.

To implement a passive channel assignment process based on notified existing assignments (in contrast to the dynamic assignment process based on actual instantaneous usage as discussed above), it is conceivable that LEO/MSS base stations could be equipped with intelligence which includes a knowledge of the terminal locations, operating frequencies and possibly hourly usage of the nearby mobile and fixed services either from look-up tables, or a frequency map indicating the inhibited area around each existing service transmitter. This map would be computed from existing system parameters, e.g. using the Spectrum Environment Assessment System (SEAS) approach, and would have to be periodically updated to reflect the changes in the existing service assignment. From the inhibition map, an available frequency map could be developed. Direct monitoring from the satellite built up over a series of passes of satellites in the constellation (assuming the satellites have sufficient sensitivity, selectivity and measurement capability) may also provide information towards compiling the available frequency map. This information could be translated into an acceptable set of channel frequencies for the sub-areas within the instantaneous coverage area. This channel information could in turn be relayed through the satellites to the terminal units. The main function of the LEO/MSS is location determination (the French document implies location determination via Doppler shift of an uplink signal at a constellation of satellites along the lines of SARSAT). Thus, individual terminal addressing capability could be an inherent feature of this prime function (however, passive location using downlink Doppler is also possible). A secondary function of the proposed system is very brief messaging which will definitely require that the system has the capability to uniquely identify and address every user. A problem with either dynamic uplink channel selection or passive geographic channel selection is that a mobile terminal can only begin to transmit once it has been informed of an appropriate transmit channel for that location and time, i.e. the mobile terminal can only initiate a call under either of two conditions;

(i) if there is a common calling channel to request a transmit channel e.g. along the lines of Channel 16 in the maritime VHF service, or

(ii) if the instantaneous pool of available channels for that location is generally available (i.e. broadcast) from the system.

Note that, in view of the visibility area and motion of the LEO satellite, the coverage areas of existing mobile and paging transmitters, and the requirement to consider over-the-horizon interference paths at these frequencies, the inhibition areas could be quite large so that the extraction of a map of acceptable frequencies could be difficult. Note also that a tremendous amount of spectrum occupancy information and terrain information (topographic, environmental and electrical characteristics) must be acquired and processed to develop the acceptable frequency map as a function of the orbital position of the LEO satellite. Time of day, sunspot activity, weather, time of year etc. could add a further time dimension to the mapping. In many situations, worst case data and conservative approximations and assumptions may simplify the process. However, in other situations, the available capacity for the LEO/MSS calculated under these pessimistic conditions may be insufficient.

Even if all this is possible, the LEO/MSS FDMA terminal units would have to possess an information processing capability and commandable frequency versatility. The cost of this distributed intelligence would inflate the cost of the LEO/MSS.

Existing fixed and mobile systems have no frequency selection intelligence and probably cannot be retrofitted. Therefore, the control problems of battling intelligence systems does not arise.

Unless the LEO/MSS system was really smart and unless there is adequate potential for geographic sharing between the LEO/MSS and existing services, there could still be potential interference problems into existing systems that employ lightly used frequencies within the dynamic assignment area. This type of interference may be acceptable since the LEO/MSS traffic will be primarily short messages (up to 100 characters, 250 msec) comprising queries and responses at fairly low data rates in individual narrow band (9 kHz) channels.

LEO/MSS INTELLIGENCE (CDMA REALIZATION)

The above comments apply mainly to the FDMA realization since, in the CDMA realization, a 1 MHz channel must be accommodated in the proposed 1.9 MHz allocation so that, for a given LEO/MSS system, there would probably be no choice of channel. Different LEO/MSS systems could employ different carrier frequencies (and/or codesets) to provide some mutual isolation and part of the allocation could be reserved for control signalling. The system intelligence could be used to limit the number of simultaneous transmissions in an area. Individual transmissions are of short duration so that a queuing algorithm may be possible. This is feasible in the case where the system has the ability to selectively address the mobile units as part of the location function. If location can be accomplished passively by the mobile units and if the secondary messaging function is an optional extra, then the requirement to limit the number of simultaneous transmissions may require sub-sets of terminals with some common identity (code) that could be addressed as a group.

In the CDMA realization, the LEO/MSS system would have a level of built-in immunity to interference from existing services. Protection to existing services could be superior to that from the FDMA realization due to the spreading of the interference over a wide bandwidth. While all simultaneous users of the LEO/MSS system would also be spread over the same wide bandwidth, they would be geographically distributed over the coverage area of the satellite and the number of users within the "coordination distance" (1.4 km per the French analysis) would be small. It is unlikely that adverse propagation conditions would enhance a majority of the dispersed transmissions outside of the coordination area. Certainly, the wanted signal could be subject to a deep fade while some of the interfering transmissions could be simultaneously enhanced but, taking into account the short duration of the interference and the fact that, if the wanted signal is faded then many of the nearby interfering signals will also be faded, the net interference could be tolerable.

PROTECTION CRITERIA

In the JIWP report, the US have quoted a pfd limit for the LEO/MSS uplink of $-120\ dBW/m^2/4\ kHz$. The concept of pfd limits for uplink allocations has little practicality since these limits are hard to translate into transmit power limitations. This is because pfd is distance sensitive and the minimum distance separation between a LEO/MSS terminal and a MS terminal or base station could be very small. The pfd in this context is also dependent upon the propagation conditions so that a typical environment and a percent of time would also have to be specified (in a downlink application, the propagation path is virtually free space, in this uplink application, the transmission path is overland). One possibility to invoke a power flux density limit for the uplink would be to require that this limit is met under specified conditions on the border between Administrations unless otherwise agreed. A refinement on this requirement would be to require that the pfd limit be met at the edge of coverage of existing services in the neighbouring Administration. This would require detailed coordination and would also restrict future growth of the existing services. Under either of these options, the onus would be on the LEO/MSS system operator to adjust the uplink transmit parameters to demonstrate that the limit can be met noting that monitoring and field detection and identification of excess interference would be very difficult owing to the short transmission bursts, low duty cycles, indeterminate locations of the transmissions and the fact that, in the FDMA case, these infrequent short bursts of interference could occur in any of the channels available to the LEO/MSS at any time.

The French document, on the other hand, suggests a more meaningful transmit power density limitation (-57 dBW/Hz for CDMA, -37 dBW/Hz for FDMA (-25 dBW/Hz from the JIWP Report)). While this form of limit is not currently employed in the Radio Regulations, it could possibly be introduced via footnote. The disadvantage of this type of limit is that it could discriminate against the use of some access and modulation methods.

ALTERNATIVE ALLOCATIONS

Discussions on possible alternate allocations are summarized in the following.

A: 400.15 - 401 MHz

A suggestion explored informally at a recent Canada/US meeting was that the band 400.15 - 401 MHz, which is currently proposed as a downlink band for the LEO/MSS, could alternately be used for the uplink. While this band is fairly clean, there is a technical problem associated with this suggestion namely the proposed 137 MHz downlink band is too far away from the suggested 400 MHz uplink band to permit common RF equipment and antenna systems (the intent is to try to use the same antenna as is currently for terrestrial radio broadcast receive systems, diversity reception would require an additional antenna preferably 0.75λ (1.5 m at 150 MHz) distant [Rep.319]). This problem also applies to the present proposal and indicates that the present 400 MHz proposed downlink band will probably not be used in conjunction with the proposed two way location determination facility. Thus, unless a companion downlink band near 400 MHz can be found, this band would serve special one-way applications only e.g. passive location determination or other one-way services such as satellite paging, information broadcast, etc.

B: 149.9 - 150.05 MHz

Another suggestion is to assign the band 149.9 - 150.05 MHz exclusively to the LEO satellite service. This band is presently allocated to Radionavigation Satellite on a primary basis in all three regions. The band may also be used by Space Research receiving earth stations. The rationale for this suggestion is that, now that GPS is becoming cost effective, it may be possible to remove the RNSS from this band in the mid 90's. This 150 MHz exclusive band would permit the partial implementation of the FDMA LEO/MSS. Thus, under this suggestion, the band 148 - 149.9 MHz could be allocated to the LEO/MSS on a non-interference basis to accommodate CDMA type systems and the band 149.9 - 150.05 MHz could be allocated on an exclusive primary basis to accommodate FDMA systems. This 150 kHz allocation falls short of the suggested requirement of 250 kHz for the FDMA realization in the JIWP Report. At the present time there are 58 assignments in Canada in this band.

C: 216 - 220 MHz

The band 216 - 220 MHz may be another possibility. This band is allocated to FIXED, MARITIME MOBILE, and Radiolocation in Region 2. This band is Land Mobile primary in Canada (FN 627A) and is used for maritime radio telephone in the US. In both cases, the band is lightly used. Pairing with the 137 - 138 MHz downlink band should allow the use of the same antenna system. However, it may still be necessary to employ separate RF stages as in the 400 MHz options. The disadvantage with this band is that it is allocated to BROADCASTING by table entry and a variety of other services for specific Administrations by footnotes in Regions 1 and 3. The broadcasting allocation would present an impossible sharing scenario. Thus, this band would not offer a worldwide facility and the satellites would have to support at least two uplink bands.

D: 160 - 162 MHz / 166 -168 MHz / 167 - 169 MHz

A cursory examination (fixed and base station licences issued in Montreal, Toronto, and Vancouver, see Figure 3) of the band 138 - 174 MHz indicates that a possible band worthy of further consideration is one of the 2 MHz bands:

a) 160 - 162 MHz (total of 1092 licences in the six districts covering the three cities)[1 2].

b) 166 - 168 MHz (total of 1006 licences in the six districts covering the three cities) [2].

c) 167 - 169 MHz (total of 1009 licences in the six districts covering the three cities) [2].

These bands are moderately used for FS and MS in these three cities compared to other 2 MHz bands and in particular compared to the present proposal in the 148 - 149.9 MHz band (1808 licences).

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1 FN 613B allocates, subject to Article 14 procedures, the band 161.3875 - 161.4125 MHz to RADIONAVIGATION in Ireland and the UK.

2 The band 162 - 174 MHz is allocated to BROADCASTING in Morocco (FN 615) which may prevent use for LEO/MSS within the visibility area around Morocco.

E: 170 - 174 MHz

On the same basis as option D above, it should be possible to find 2 MHz of shared spectrum in the band 170 - 174 MHz (453, 450, 450, and 235 licences in the four 1 MHz bands). The drawback from an international point of view is that this band is allocated to BROADCASTING in several countries (FN 617, 618). Also, the upper adjacent band is allocated to BROADCASTING internationally which may cause filtering problems in the satellite receiver.

CONCLUSIONS

It would appear that the chances of achieving a useful VHF allocation for the LEO/MSS on a worldwide basis or even on a Canada wide basis are very slim particularly for the FDMA realization of this service. It may therefore be necessary to consider Regional allocations and/or frequencies in higher bands such as near 400 MHz or perhaps 800 MHz and accept the added complexity imposed on the satellites and vehicle mounted equipment.

Dynamic channel assignment based on real-time measurements at the satellite to provide acceptable performance for the LEO/MSS in the FDMA realization may be very difficult, costly, and of limited benefit with respect to protecting existing services in the proposed 148 - 149.9 MHz band since;

a) these measurements would be unlikely to differentiate between lightly used and unused channels,

b) measurements at LEO do not provide a meaningful indication of the possible vulnerability of existing terrestrial services and measurements of the local environment by the LEO/MSS terminal is not practical,

c) the intelligence required to protect existing services based on notification and licence information and propagation predictions could be prohibitive, and

d) any form of time sharing arrangement (e.g. by mutual agreement or by retrofitting compatible intelligence in the MS and FS systems) would be difficult if not impossible to implement post-facto.

In the proposed band, 148 - 149.9 MHz, the LEO/MSS would have to employ a combination of low transmit powers, message lengths, duty cycles, and traffic densities, and possibly employ offset carriers or spread spectrum modulation techniques to protect existing services in a frequency shared situation.

It would be necessary to institute appropriate Radio Regulations to reflect these requirements. For example, by inclusion of a Footnote in Article 8, similar to the one suggested for the downlink, indicating that the LEO/MSS shall not cause harmful interference to existing services (and, under RR 435, cannot claim protection from harmful interference from existing services). In addition, a Resolution to mandate the CCIR to derive appropriate sensitivity thresholds, in terms of (aggregate) eirp density